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THE OPTIMISATION OF THE COLOUR ANALYSIS OF MICROWAVE-DRIED TOMATOES APPLYING THE TAGUCHI TECHNIQUE

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Abstract: Food processors and consumers frequently worry about the inconsistent colour of dried tomatoes. To minimize detrimental color changes, process parameters need to be optimized. Thus, digital imaging with the Photoshop software and optimization with the Taguchi technique were explored to determine the surface color of microwave-dried tomato slices. The tomato sample was pretreated with water blanching (WB), ascorbic acid (AA) and sodium metabisulphite (SB). In addition, the sample was cut into 4-mm, 6-mm and 8-mm thicknesses and dried at 90W, 180W and 360W microwave power levels following the Taguchi experimental design. Color characteristics (L^*, a^*, b^*, change in color, browning index, hue, and chroma) of the dried tomato slices were determined. The L^*, a^*, and b^* values of fresh tomatoes were 56.73, 44.51, and 38.38, respectively. The optimum processing conditions for the color characteristics varied significantly ($p< 0.05$). Pretreatment is the prime significant processing parameter controlling the L^*, b^*, ΔE, BI, and hue values. At the same time, the slice thickness considerably influenced the a^* value, the ratio of a^*/b^* and chroma values. The digital imaging color measurements of dried tomato slices provide a suitable method for non-destructive color analysis. The ability to upgrade and modify tomato processors so they can accommodate bulk color characteristics will be made possible by this knowledge.

Key words: color analysis, microwave drying, tomato slice, Adobe Photoshop, Taguchi technique.

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Introduction

The colour of any material is the human perception of light waves as reflected from that material surface. It was considered a key role in food choice and preference acceptability. It could influence taste thresholds, sweetness perception and pleasantness (Kulanthaisami et al., 2010). Thus, it is a good quality indicator of fresh and dried tomato products that influences consumer acceptability. The colour change in tomatoes during the drying operation was reportedly caused by the reactions taking place inside it, such as pigment degradation (carotenoids) and browning reactions (Maillard reaction and oxidation of ascorbic acid) (Ashebir et al., 2009). Therefore, the extent of the effects of drying on tomato quality can be evaluated by the final values of colour parameters.

The determination of the colour of food materials can be done either subjectively by visual (human) inspection or objectively through colour measuring instruments. The subjective systems involve comparison with coloured references under controlled illumination. Colour standards are often used as reference materials and require more specialised trained observers. Unfortunately, it implies a slower inspection and varies from observer to observer (Afshari-Jouybari and Farahnaky, 2011). Based on these reasons, the objective method of determining colour through colour measuring instruments is preferred. The commonly used devices for food colour analysis are the Hunter lab colorimeter, Minolta colorimeter and Dr Lange colorimeter. However, these instruments can only measure small samples and are often unsuitable for large food products like fruits and vegetables (Tarafdar et al., 2018). Yam and Papadakis (2004) have reported that these colorimeter instruments are designed mainly for quality control, providing average measurement values. It would be difficult and time-consuming if used for point-by-point measurement at many locations to obtain colour distribution, thereby making them not well suited for food engineering research. Also, some of these colorimeter instruments require destructing the food samples before measurements; that is, the food samples need to be homogenised using a grinder or a blender to achieve uniform colour distributions. This grinding or blending takes time and renders the food sample no longer usable for other purposes.

Food sample colour parameters are usually measured in RGB (Red, Green and Blue) or Commission Internationale d'Eclairage (CIE) Lab colour space. The RGB colour space consists of a three-dimensional rectangular coordinate system with R, G and B axes (Figure 1a). These three components per pixel represent a colour image in RGB format with the range 0–255 and their intensity is electronically combined to produce a digital colour picture. Different proportions and intensities of RGB colours are used to create cyan, magenta, yellow, and white (Yam and Papadakis, 2004). The available hardware for colour image processing, such as colour sensors, monitors and digital cameras, are geared to RGB colour space. The CIE, in 1976, developed the L^*, a^*, b^* model for colour measurement, which consists of a lightness or luminance component (L^* value, ranging from 0 to 100), along with two chromatic components (ranging from – 120 to +120) (Figure 1b). The a^* component changes from $-a$ (greenness) to $+a$ (redness), while the component b^* changes from $-b$ (blueness) to $+b$ (yellowness). The L^*, a^*, b^* colour is device independent, thereby giving coherent colour despite the input or output devices like a digital camera, a scanner, a monitor, and a printer (Yam and Papadakis, 2004). This characteristic gives it an advantage over other modes of colour measurement. The L^*, a^*, b^* values are often used in food research studies (Al-Sulaiman, 2011; Idris et al., 2013; Talih et al., 2017; Ilter et al., 2018; Komolafe et al., 2019).

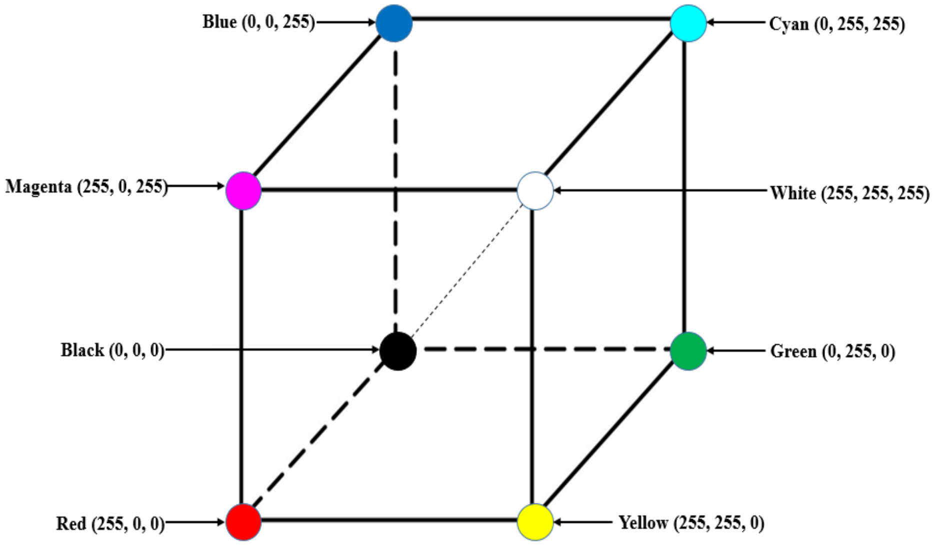


Figure 1a. The RGB colour model.

Nowadays, digital imaging, computer vision, and spatial image acquisition methods have been used in the food processing industries for quality evaluations, identifications, detection of defects, grading and sorting of fruits and vegetables and other prepared goods (Afshari-Jouybari and Farahnaky, 2011). However, most of these methods utilise sophisticated instruments, control systems, and algorithms that are not easily accessible or expensive and sometimes unavailable at the research level (Tarafdar et al., 2018). These have led to the search for a simple, low-cost and robust imaging technique capable of detecting colour values in food samples. Several researchers carried out studies to analyse the visual characteristics of food samples with the use of a digital camera along with image analysis software like Adobe Photoshop and computer vision (Yam and Papadakis, 2004; Mendoza et al., 2006; Afshari-Jouybari and Farahnaky, 2011; Makino et al., 2016; Tarafdar et al., 2018). However, applying these widely used methods in image analysis to optimise complex food processes like microwave drying to produce good products with acceptable colour characteristics still needs to be explored.

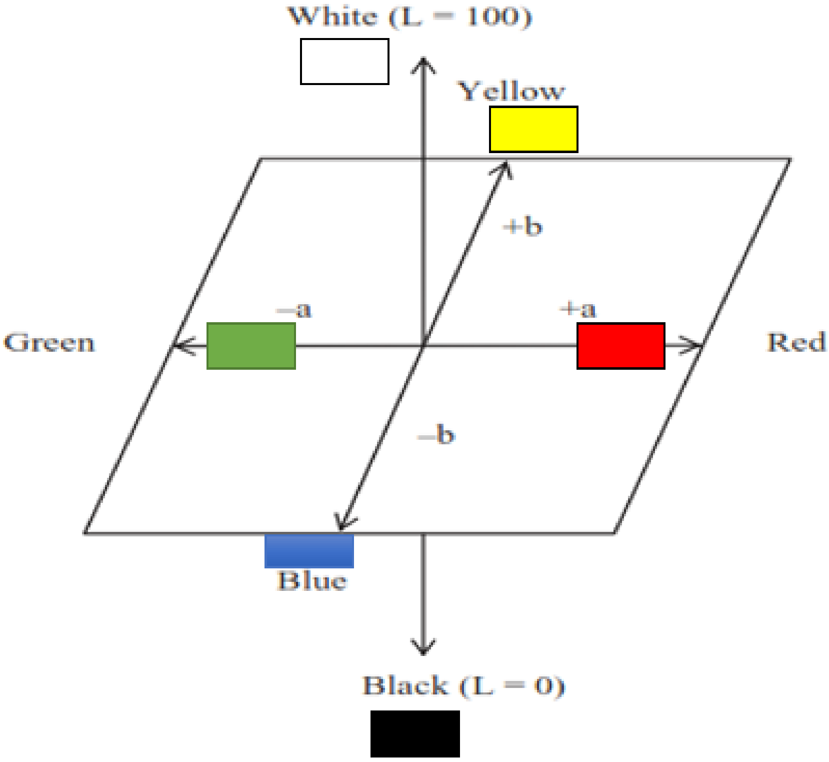


Figure 1b. The CIELAB L^* a^* b^* colour system.

Microwave drying works on the principle of electromagnetic energy, which travels in high-frequency waves that range between 300 GHz and 300 MHz. When a dielectric material is placed in an electromagnetic field, the material becomes polarised and stores electric energy through polarisation. The level and mechanism of polarisation available to materials depend on the state and composition of the material and the frequency of the applied electric field (Adu et al., 1995). The transformation of electromagnetic energy into kinetic molecular energy generates heat within the material, making heat migration to the core of the product and mass migration of water out of the material more accessible. This volumetric heating makes microwave drying perform more uniformly and faster than conventional drying systems. Temperature gradients do not govern microwave drying, but the heat arises from the oscillation of molecular dipoles and the movement of ionic constituents, respectively, in response to alternating electric fields at high frequencies. The resulting energy is absorbed throughout the volume of the wet material. The rise in internal pressure drives out the moisture from the interior to the material surface (Sanga et al., 2000). Microwave drying is caused by dielectric heating alone, but most microwave drying joins microwave and conventional heating. The heating might be separate or simultaneous (Hussein et al., 2019).

Microwave drying offers several benefits, including developing desirable characteristics in dry products due to the volumetric heating, a high drying rate, and effective heat distribution throughout the material (Sanga et al., 2000). However, microwave drying induces changes in the physical and chemical compositions of the materials. These include the changes in colour, aroma, rehydration ratios and the loss of water-soluble vitamins (mainly ascorbic acid). Therefore, processing parameters are optimised to control the quality, productivity, and drying conditions to minimise detrimental quality changes during processing. Also, determining a good design requires using a strategically designed experiment that exposes the process to various levels of design parameters.

The experimental design technique of Genichi Taguchi that was explicitly devised to improve the quality of Japanese manufactured goods in the post-war period in conjunction with analysis of variance (ANOVA) has been highly successful (Karna and Sahai, 2012). The technique optimises any complex process like drying to produce high-quality dried products at subsequently low cost. The Taguchi technique uses a particular set of arrays known as orthogonal, which means not mixed or separated factors (Taguchi, 1990; Dash et al., 2016). These orthogonal arrays give a minimum number of experimental runs providing a representative of a whole variable. The signal-to-noise (SN) ratio in the Taguchi technique measures the effect of noise factors on performance characteristics and quantifies the variability. Several researchers have successfully applied the Taguchi technique to optimise some complex processes: optimisations of process factors in the production of ready-to-eat peanut chutney (Chandrasekar et al., 2015), frying of potato slices in the microwave (Naik et al., 2017), microwave drying of tomato slices (Hussein et al., 2019), milling quality of brown rice (Sanusi et al., 2020) and drying of tomato slices in the hot-air dryer (Hussein et al., 2020). Despite these applications of the Taguchi technique in optimisation, there needs to be more information available on applying the Taguchi technique in investigating the effect of processing parameters on the colour of microwave-dried tomato slices. Therefore, this study used the Taguchi technique to determine the optimum drying conditions to preserve the colour of microwave-dried tomato slices.

Material and Methods

The UTC varieties of tomatoes used in this study were obtained from the Teaching and Research Farm of the Modibbo Adama University of Technology, Yola, Adamawa State, Nigeria. The appearance, firmness, and size uniformity served as the basis for selection from the lot.

Sample preparation

The ripeness and maturity tests of the tomatoes were determined as described by Choi et al. (1995). Colour measurement was performed on the surface of the tomatoes with the aid of a Minolta Chroma Meter CR-200 (Minolta Camera Co., Ltd., Osaka, Japan) tristimulus colour analyser, this was replicated four times. The readings were obtained in the CIE L^* a^* b^* colour space and the coordinates L^*, a^*, and b^* were determined with the D65 standard observer at a visual angle of 10°C. Tomatoes with similar coordinates were selected to use fruit with homogeneous ripeness. The maturity stage of the tomato was determined by checking the total soluble solid (% Brix) with an Abbe Refractometer (AOAC, 2016). A Kenwood blender (Philips HR 2001, China) was used to blend the fresh tomatoes. The resulting blended tomato was then centrifuged at 1500 rpm for 10 minutes, and the supernatant was used. The refractometer prism was rinsed, zeroed with distilled water, and wiped dry with cotton wool. Two drops of supernatant were placed on the refractometer prism and viewed through the eyepiece. The determination was replicated three times, and the average result was 6.67 ± 0.26 Brix. The titratable acidity was 0.33, and the maturity index (ratio of total soluble solid to titratable acidity) was 20.21.

The pretreatment of tomatoes

Tomatoes were thoroughly cleaned by washing under tap water. After that, they were rinsed with distilled water and wiped with a tissue towel, as described by Hussein et al. (2016). Twelve (12) kg of tomatoes were subjected to each water blanching (WB) for 1 minute, 5% w/v of ascorbic acid treatment (AA), and 5% w/v of sodium metabisulphite treatment (SM) for 5 minutes. The ratio of tomatoes to dipping solution – 1:10 (w/v), as used by Hussein et al. (2020), was adopted. After the pretreatment process, each portion was sliced to a thickness of 4, 6, and 8 mm, respectively, with the aid of a Tomato Slicer (NEMCO 56610-13/16” Roma).

The Taguchi experimental plan

The Taguchi experimental plan was designed with the Minitab 16 (Minitab, Inc. Coventry, UK) software for three factors at three levels, having an array of L9 (3x3). The outline that gave nine experimental runs was obtained and used to evaluate the responses of the colour changes with the interactions between pretreatment, slice thickness, and microwave power, as presented in Table 1.

The drying procedure

The pretreated samples were dried at three levels of microwave powers of 90, 180, and 360 W with thicknesses of 4, 6, and 8 mm according to the experimental runs in Table 1. The superficial fluid on the surface of the pretreated samples was blotted with a paper towel. A pretreated tomato slice of 200 g was uniformly spread in a single layer on a 30-cm diameter glass dish with about 1 cm depth and was placed at the centre of the microwave. The glass dish was rotated in the microwave chamber during operation to allow the even absorption of microwave energy by the drying samples. The microwave oven was operated for a 5-minute ON cycle and a 25-minute OFF cycle for the first hour and 1-minute ON and 5-minute OFF intervals for the subsequent drying times, as described by Hussein et al. (2019). The oven output power and processing time adjustment were made with a digital control facility in the microwave oven.

The sample was turned over at 15-minute intervals. The weight loss was taken at 5-minute intervals with the digital electronic scale (OEM, Freebang-SKU323367). Based on the preset microwave output power and schedule, the experiment was replicated three times, and the data gave the average results. The point when subsequent weight reduction was less than 0.001 g was taken as the final drying stage. After drying, the samples were packed and sealed in black polythene to prevent light and stored until further analyses.

Table 1. The outline of the Taguchi experimental design L_9 (3x3) for microwave oven drying.

Experimental runs	Independent variables in coded form			Experimental variables in their natural units		
	A	B	C	Pretreatment	Thickness (mm)	Microwave power (W)
1	1	1	1	WB	4	90
2	1	2	2	WB	6	180
3	1	3	3	WB	8	360
4	2	1	2	AA	4	180
5	2	2	3	AA	6	360
6	2	3	1	AA	8	90
7	3	1	3	SM	4	360
8	3	2	1	SM	6	90
9	3	3	2	SM	8	180

Colour measurements

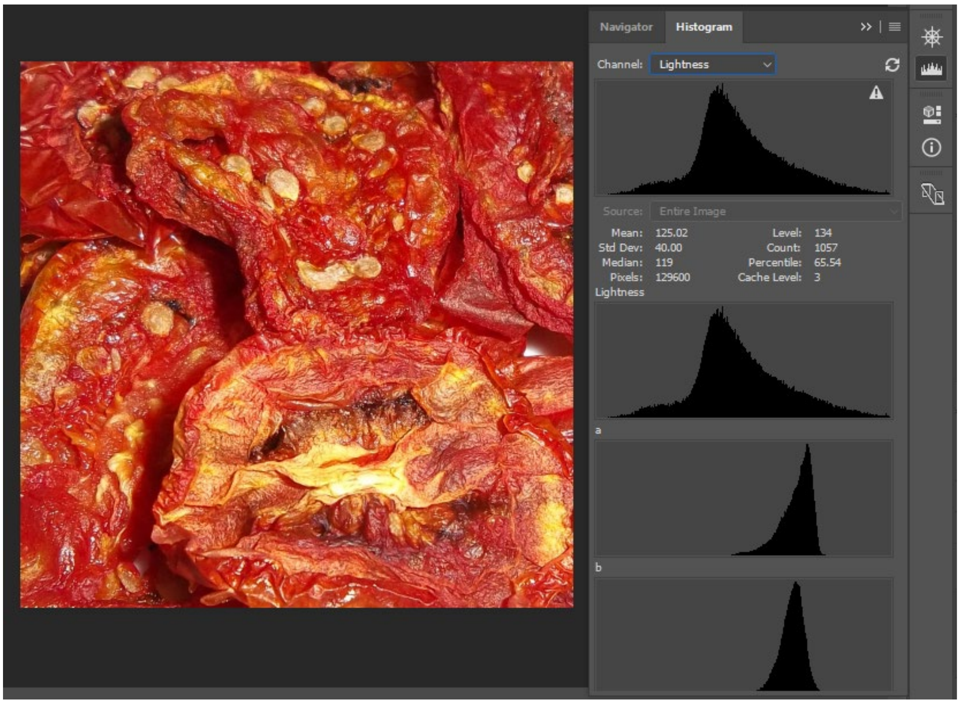
The simple digital imaging method described by Yam and Papadakis (2004) and Al-Sulaiman (2011) was adopted. A high-resolution digital camera (Canon XUS105, 12.0 MegaPixel, 4 digital zooms) was used to snapshot the dried tomato sample images under two 40 W fluorescent lamps. The images were captured in a semi-controlled environment. The camera was staged perpendicular at a distance of 60 cm. At the same time, the dried samples were illuminated at 45° above and 45°

to the right or left of the viewing axis. They were rendered with and without cast shadows. The colour was then analysed quantitatively using Photoshop (Adobe-Systems, 2015). The histogram window of Photoshop was used to estimate the colour distributions along the x-axis and the y-axis. The histogram window displays the statistics (mean, standard deviation, median, percentage, etc.) of the colour value and lightness (L) of a selected area in the image of dried tomato samples. The statistics for the two other colour values (a and b) were also displayed by the histogram window by choosing a and b under the channel drop-down menu (Figure 2). The colour values for L, a, and b that were determined from the histogram window are not standard colour values. Thus, they were converted to the standard colour values (L^*, a^*, and b^*) using the formulas 1, 2, and 3 (Yam and Papadakis, 2004). The lightness is the L^*, the redness is the a^*, while the yellowness is the b^*.

$$L^* = \frac{lightness}{255} \times 100 \tag{1}$$

$$a^* = \frac{240a}{255} - 120 \tag{2}$$

$$b^* = \frac{240b}{255} - 120 \tag{3}$$



Channel: Lightness

Source: Entire Image

Mean: 125.02
Std Dev: 40.00
Median: 119
Pixels: 129600
Level: 134
Count: 1057
Percentile: 65.54
Cache Level: 3

Figure 2. The histogram window displays for the statistics of the microwave-dried tomatoes.

The determination of a^*/b^*, chroma (C) and hue angle (α)

The ratio of a^* to b^*, which is an indicator of tomato ripeness, was determined as described by Al-Sulaiman (2011). The chroma and hue angle were also estimated and used to describe the tomato colour changes after drying (Dadali et al., 2007; Karaaslan and Tuncer, 2008).

$$Ratio\ of\ a^* to\ b^* = \frac{a^*}{b^*} \tag{4}$$

$$C = \sqrt{(a^*)^2 + (b^*)^2} \tag{5}$$

$$\alpha = tan^{-1}(\frac{a^*}{b^*}) \tag{6}$$

The determination of the total colour change (ΔE)

The fresh tomato was used as the ideal sample, while the total colour change (ΔE) was estimated as described by Dadali et al. (2007):

$$\Delta E = [(L^* - L^{**})^2 + (a^* - a^{**})^2 + (b^* - b^{**})^2]^{0.5} \tag{7}$$

where;
ΔE = the total colour change of the dried tomato slices;
L^* and L^{**} = the lightness of fresh and dried tomato samples;
a^* and a^{**} = the redness of fresh and dried tomato samples;
b^* and b^{**} = the yellowness of fresh and dried tomato samples.

The determination of the browning index (BI)

The browning index (BI) gave the brown colour purity and was estimated as described by Dadali et al. (2007).

$$BI = \frac{[100(x-0.31)]}{0.17} \tag{8}$$

where; $x = \frac{(a^{**}+1.75L^{**})}{(5.645L^{**}+a^*-3.012b^{**})}$

The Taguchi orthogonal array optimisation technique

The Taguchi method suggests the production processes have minor variability as the optimal condition. The variability is expressed by the signal-to-noise (S/N) ratio. The S/N ratio represents quality characteristics for the observed data in the Taguchi technique. The S/N ratio serves as an index to estimate the quality of the production processes. The 'signal' stands for the desired value, the 'noise' stands for the undesirable value, and the signal-to-noise ratio represents the scatter around the expected values (Hussein et al., 2019). The smaller, the better S/N ratio was used to optimise data obtained for BI and ΔE, while the larger, the better S/N ratio was adopted for L^*, a^*, b^*, a^*/b^*, chroma, and hue by using equations 9 and 10, respectively.

The smaller, the better S/N ratio property

$$S/N = -10log\frac{1}{n}(\sum y^2) \tag{9}$$

The larger, the better S/N ratio property

$$S/N = -10log\frac{1}{n}(\sum \frac{1}{y^2}) \tag{10}$$

where: n = the number of experimental runs, y = the response data.

The average mean of the response and the S/N ratio for each level of the factors were calculated by taking the average of the mean values of the response of the treatments. The optimal level of the processing parameters (pretreatment, slice thickness and microwave power) and the adequate processing combinations within the experimental realm were identified.

Results and Discussion

The optimisation of the effect of the drying conditions on the colour of the microwave-dried tomato slice

The colour of the fresh tomato was determined, and the average values of $L*$, $a*$, and $b*$ were 56.73, 44.51 and 38.38, respectively. The photograph of the pretreated microwave-dried tomatoes is depicted in Figure 3. The changes in the colour of the pretreated microwave dried tomato slices are shown in Tables 2 a and 2 b. It is shown that the brightness ($L*$) ranged from 31.06 to 48.83. It was observed that the dried slices were slightly darker ($L*$ decreased) when compared to fresh tomatoes. The brightness of the dried tomato slices decreased at each drying microwave power examined. This trend shows that the luminance of the tomato slices reduced after drying. Similar decreases in the brightness of dried tomato slices were reported by Izli and Isik (2015). The higher the S/N ratio, the better it was chosen to optimise the $L*$ value. The largest S/N ratio (33.77) was acquired for the WB pretreated and 4-mm thick slice at 90 W microwave powers. In comparison, the smallest S/N ratio (29.85) was acquired for the AA pretreated and 6-mm-thick slice at 360 W microwave power. This showed that the pretreatment with WB and the 4-mm-thick tomato slice at 90 W microwave power were the prime processing combination in the experimental realm.

The effect of each processing factor on the dried tomato brightness was established by calculating the desired factor levels by the S/N ratio from the Taguchi analysis. The response means of the S/N ratio for each level of the controlling factors are shown in Tables 3a and 3b. The response means of the S/N ratio show that the pretreatment used had the largest delta value; thus, the 1st rank was allocated to it, followed by the thickness (the 2nd rank) and microwave power (the 3rd rank). This shows that pretreatment was the prime significant processing parameter controlling the $L*$ of the tomato slice. At the same time, the thickness of the slice and the microwave power followed, respectively. The redness (*a**) and yellowness (*b**) slightly decreased when compared to fresh tomatoes (Table 2a). Namely, there was a slight degradation of the pigments of microwave-dried tomatoes. This little pigment degradation was consistent with the report by Qadri and Srivastava (2014) for microwave oven drying of tomatoes. Izli and Isik (2015) also reported pigment degradation in the microwave, convective, and microwave-convective oven drying of tomatoes. The decrease in the pigment of dried tomatoes compared to fresh ones could be linked to the reactions between the reducing sugars and amino acids in the tomato during drying (Abano et al., 2011).

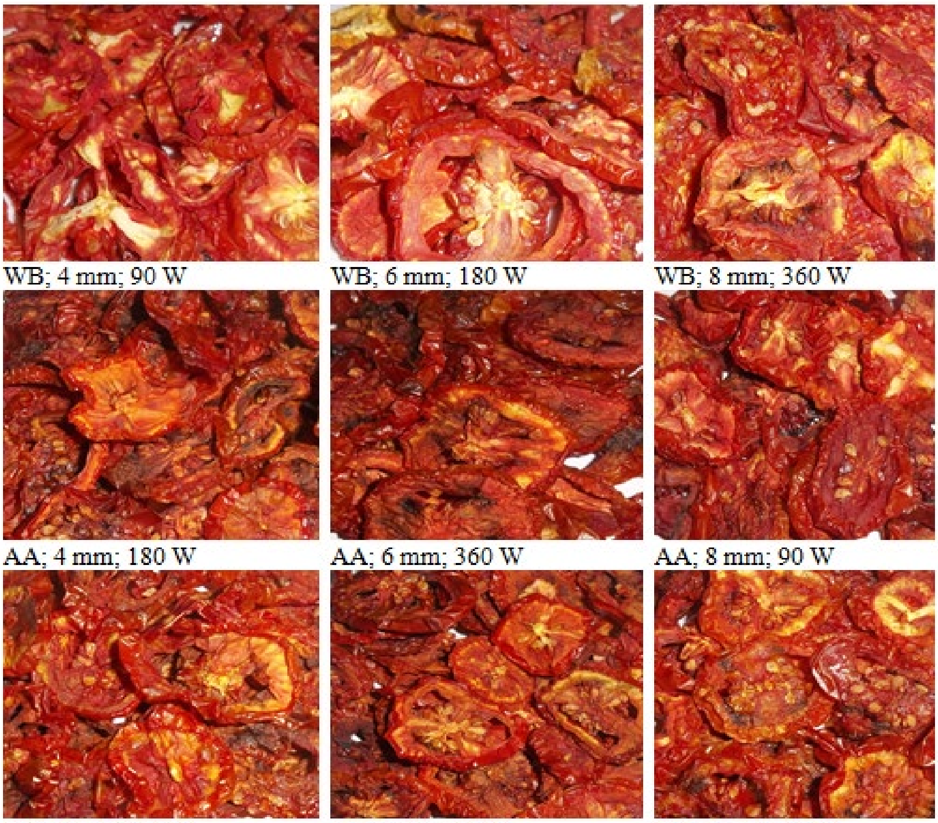

WB; 4 mm; 90 W
WB; 6 mm; 180 W
WB; 8 mm; 360 W
AA; 4 mm; 180 W
AA; 6 mm; 360 W
AA; 8 mm; 90 W
SM; 4 mm; 360 W
SM; 6 mm; 90 W
SM; 8 mm 180 W

Figure 3. Microwave-dried tomatoes.

The larger the S/N ratio, the better was chosen to optimise the *a** and *b** values of the dried tomatoes. The largest S/N ratio (32.98 for *a** and 32.12 for *b**) was obtained for the WB pretreated and 4-mm-thick slice at 90 W microwave power. This showed that the pretreatment with WB and the 4-mm-thick tomato slice at 90 W microwave power were the prime processing combination to preserve the red and yellow pigments of the tomato. The response means of the S/N ratio for each level of the controlling factors in $a*$ and $b*$ are shown in Table 2a. Regarding $a*$, the response means of the S/N ratio indicate that the thickness of the slice had the largest delta value; thus, the 1st rank was allocated to it, followed by pretreatment (the 2nd rank) and microwave power (the 3rd rank). This indicates that the slice thickness was the prime significant processing parameter controlling the $a*$ of the tomato slice, while pretreatment and the microwave power used followed, respectively. Regarding $b*$, the response means of the S/N ratio indicate that pretreatment had the largest delta value; thus, the 1st rank was allocated to it, followed by the thickness of the slice (the 2nd rank) and microwave power (the 3rd rank). This indicates that pretreatment was the prime significant processing parameter controlling the $b*$ of the tomato slice. In addition, the thickness of the slice and the microwave power used followed, respectively.

Table 2a. The effect of drying conditions on the colour parameters of pretreated microwave-dried tomatoes using the Taguchi technique.

Experimental runs	$L*$	S/N $L*$	$a*$	S/N $a*$	$b*$	S/N $b*$	$a*/b*$	S/N $a*/b*$
Fresh	56.73 ± 3.08^{a}		44.51 ± 3.14^{a}		38.38 ± 2.00^{ab}		1.16 ± 0.02^{ab}	
WB; 4 mm; 90 W	48.83 ± 1.66^{b}	33.77	44.56 ± 0.94^{a}	32.98	40.34 ± 1.06^{a}	32.12	1.11 ± 0.01^{bc}	0.91
WB; 6 mm; 180 W	48.65 ± 0.34^{b}	33.74	41.23 ± 0.47^{ab}	32.30	38.67 ± 0.23^{ab}	31.75	1.07 ± 0.01^{c}	0.59
WB; 8 mm; 360 W	47.77 ± 1.62^{bc}	33.58	42.02 ± 0.37^{ab}	32.47	38.43 ± 0.82^{ab}	31.69	1.09 ± 0.01^{bc}	0.75
AA; 4 mm; 180 W	41.62 ± 0.38^{bcd}	32.39	40.47 ± 0.27^{abc}	32.14	37.86 ± 0.42^{ab}	31.56	1.07 ± 0.02^{c}	0.59
AA; 6 mm; 360 W	38.91 ± 1.45^{d}	29.85	36.81 ± 0.48^{c}	31.32	31.03 ± 0.98^{c}	29.84	1.19 ± 0.02^{a}	1.51
AA; 8 mm; 90 W	41.53 ± 2.30^{bcd}	32.37	42.14 ± 1.07^{ab}	32.49	35.38 ± 1.34^{b}	30.98	1.19 ± 0.02^{a}	1.51
SM; 4 mm; 360 W	42.08 ± 2.25^{bcd}	32.48	41.60 ± 0.88^{ab}	32.38	38.69 ± 1.82^{ab}	31.75	1.08 ± 0.03^{c}	0.67
SM; 6 mm; 90 W	40.97 ± 3.72^{bc}	32.25	39.79 ± 0.80^{bc}	32.00	37.56 ± 2.06^{ab}	31.50	1.06 ± 0.04^{c}	0.51
SM; 8 mm; 180 W	36.70 ± 3.42^{d}	31.29	38.56 ± 1.52^{bc}	31.72	35.46 ± 1.98^{b}	30.99	1.09 ± 0.02^{c}	0.75

Mean values in the same columns bearing the same superscript are not significantly different ($p<0.05$).

The ratio of $a*/b*$ of tomatoes indicates the end product redness. It is used as an index for colour and it is positively correlated with the lycopene content (Zanoni et al., 1999; Idris et al., 2013). Idris et al. (2013) reported that the ratio of $a*/b*$ value of more than 1 indicates an excellent red colour, while lower values denote immaturity or deterioration in colour. Table 2a shows that the value of $a*/b*$ decreased significantly ($p>0.05$) in both WB and SM pretreated tomatoes compared to the fresh sample. However, an increase in the value of $a*/b*$ was observed for AA pretreated tomatoes and it was slightly higher than the fresh sample. A decrease in the $a*/b*$ value after air-drying of tomato was reported by

Kerkhofs et al. (2005). However, an increase in the value of *a*/b** was reported by Ashebir et al. (2009).

The larger the S/N ratio, the better was chosen to optimise the value of *a*/b** of the dried tomatoes. The largest S/N ratio was acquired for the AA pretreated and 6-mm thick slice at 360 W microwave powers and the AA pretreated and 8-mm thick slice at 90 W microwave powers. These were the prime processing combinations to preserve the brightness of the tomato. The response means of the S/N ratio for each level of the controlling factors in *a*/b** (Table 2a) show that the pretreatment had the largest delta value; thus, the 1st rank was allocated to it, followed by microwave power used (the 2nd rank) and slice thickness (the 3rd rank). This indicates that the pretreatment used was the prime significant processing parameter controlling the brightness of the dried tomato slice. The microwave power used and the slice thickness followed, respectively.

The overall colour change (ΔE) was calculated to find the difference between the dried tomato sample colour and the fresh ones. ΔE was significantly higher at higher microwave power and slice thickness than at lower microwave power and slice thickness (Table 2b). This implies that an increase in microwave power and slice thickness increases the degradation rate faster, resulting from high electromagnetic energy absorption by the tomatoes. An increase in ΔE value was observed for the AA pretreated (15.67 to 27.80) followed by the SM pretreated (15.24 to 21.24) and the WB pretreated (8.43 to 9.38) tomatoes. This showed that more pronounced changes were observed in the colour of AA treated samples than in SM and WB treated samples. Gnanasekharan et al. (1992) reported that the colour of tomato changes could be linked to the gradual changes in the three coordinates (lower '**L*' and '**b*'; less negative '**a*'). Talih et al. (2017) have also reported that a dried black carrot pulp brightness value decreases with increasing microwave powers and decreasing the sample thickness. The degradation of the pigments or browning reactions may be related to pigment destruction and may cause colour loss (**L*).

The smaller the S/N ratio, the better was chosen to optimise the ΔE value (Table 2b). The largest S/N ratio (-18.52) was acquired for the WB pretreated and 4-mm-thick slice at 90 W microwave power. In comparison, the smallest S/N ratio (-28.88) was acquired for the AA pretreated and 6-mm-thick slice at 360 W microwave power. This indicates that the pretreatment with the WB and 4-mm thick tomato slice at 90 W microwave power were the prime processing combination. The response means of the S/N ratio for each level of the controlling factors in ΔE (Table 2b) show that the pretreatment of the slice had the largest delta value; thus, the 1st rank was allocated to it, followed by thickness of the slice (the 2nd rank) and microwave power used (the 3rd rank). This suggests that the pretreatment used was the most critical processing factor influencing the overall colour change of the dried tomato slice. The microwave power used and the thickness of the slices followed, respectively.

Table 2b. The effect of drying conditions on the colour parameters of pretreated microwave-dried tomatoes using the Taguchi technique.

Experimental runs	ΔE	S/N ΔE	BI	S/N BI	*C*	S/N *C*	hue(α)	S/N hue(α)
Fresh	-		-		58.77 ± 3.68^{a}		0.86 ± 0.01^{ab}	
WB; 4 mm; 90 W	8.43 ± 1.52^{d}	-18.52	32.01 ± 3.76^{ab}	-30.11	60.11 ± 1.40^{a}	35.58	0.84 ± 0.01^{bc}	-1.51
WB; 6 mm; 180 W	8.74 ± 0.47^{d}	-18.83	39.82 ± 0.81^{a}	-32.00	56.51 ± 0.48^{ab}	35.05	0.82 ± 0.01^{c}	-1.72
WB; 8 mm; 360 W	9.38 ± 1.66^{cd}	-19.44	36.26 ± 2.87^{a}	-31.19	56.94 ± 0.82^{ab}	35.11	0.83 ± 0.01^{bc}	-1.62
AA; 4 mm; 180 W	15.67 ± 0.31b^{cd}	-23.90	21.50 ± 1.40^{bcd}	-26.65	55.42 ± 0.26^{ab}	34.87	0.82 ± 0.01^{c}	-1.72
AA; 6 mm; 360 W	20.77 ± 1.76^{a}	-28.88	31.56 ± 2.57^{ab}	-29.98	48.15 ± 1.01^{c}	33.65	0.87 ± 0.01^{a}	-1.21
AA; 8 mm; 90 W	15.76 ± 2.61^{bcd}	-23.95	22.36 ± 3.70^{bc}	-26.99	55.02 ± 1.68^{ab}	34.81	0.87 ± 0.01^{a}	-1.21
SM; 4 mm; 360 W	15.24 ± 2.15^{bcd}	-23.66	19.50 ± 2.5^{c}	-25.80	56.82 ± 1.89^{ab}	35.09	0.82 ± 0.01^{c}	-1.72
SM; 6 mm; 90 W	16.75 ± 3.76^{bc}	-24.48	20.30 ± 7.16^{bc}	-26.15	54.74 ± 1.99^{ab}	34.76	0.82 ± 0.02^{c}	-1.72
SM; 8 mm; 180 W	21.24 ± 3.85^{ab}	-26.55	11.78 ± 5.56^{c}	-21.42	52.39 ± 2.45^{bc}	34.39	0.83 ± 0.01^{c}	-1.62

Mean values in the same columns bearing the same superscript are not significantly different ($p<0.05$).

The browning index (BI) was evaluated as the extent of browning in the dried tomatoes. Cernisev (2009) has reported that the browning reaction significantly causes tomato quality degradation during the drying process. The BI ranged from 11.78 to 39.82, with experiment 2 (WB; 6 mm; 180 W) having the highest value while experiment 8 (SM; 6 mm; 90 W) had the lowest value. These results (Table 2b) clearly show that the processing conditions significantly affected tomato browning reactions. The rate of colour formation increased as the intensity of the drying process increased. This observation corroborated the BI of microwave-dried black carrot pulp, as Talih et al. (2017) reported. It was observed that the pretreatment used reduced the BI considerably, and the BI reduced as the slice thickness and the drying time reduced.

The smaller the S/N ratio, the better was chosen to optimise the BI value (Table 2b). The largest S/N ratio (-21.42) was acquired for the SM pretreated and 6-mm thick slice at 90 W microwave power. In comparison, the smallest S/N ratio (-32.00) was acquired for the WB pretreated and the 6-mm thick slice at 180 W microwave power. This indicates that the pretreatment with SM and 6-mm tomato thick slice at 90 W microwave power were the prime processing combination. The response means of the S/N ratio for each level of the controlling factors in BI (Table 3b) show that the pretreatment of the slice had the largest delta value; thus, the 1st rank was allocated to it, followed by thickness of the slice (the 2nd rank) and microwave power used (the 3rd rank). This indicates that the slice pretreatment was the prime significant processing parameter controlling the browning change in the dried tomato slice. The thickness of the slice and the microwave power used followed, respectively.

Table 3a. The response means of the signal to noise (S/N) ratio for colour parameters of microwave oven drying.

	Pretreatment	Thickness	Microwave power
*L** (using larger the better)			
Level 1	33.70	32.88	32.80
Level 2	31.18	32.60	32.47
Level 3	32.01	32.41	32.62
Delta	1.69	0.47	0.32
Rank	1st	2nd	3rd
*a** (using larger the better)			
Level 1	32.58	32.50	32.49
Level 2	31.99	31.87	32.06
Level 3	32.03	32.23	32.06
Delta	0.60	0.63	0.43
Rank	2nd	1st	3rd
*b** (using larger the better)			
Level 1	31.85	31.81	31.53
Level 2	30.79	31.03	31.44
Level 3	31.41	31.22	31.09
Delta	1.06	0.78	0.43
Rank	1st	2nd	3rd
a/b** (using larger the better)			
Level 1	0.75	0.72	0.98
Level 2	1.20	0.87	0.64
Level 3	0.64	1.00	0.98
Delta	0.56	0.28	0.34
Rank	1st	3rd	2nd

Key: Level 1 = Water blanched, 4-mm thickness and 90 W microwave power; Level 2 = Ascorbic acid, 6-mm thickness and 180 W microwave power; Level 3 = Sodium metabisulphite, 8-mm thickness and 360 W microwave power.

Chroma (*C*) values (Table 2b) were observed to decrease and closely followed the same reduction pattern with *b** values. The *C* value indicates the level of colour saturation and is proportional to the strength of the colour. Slight changes were observed in the *C* values of WB pretreated samples compared with the fresh tomato. However, they differed significantly ($p<0.05$) from each other. This indicates the stability of the red colour of the dried pretreated tomato. Similar observations were reported by Barreiro et al. (1997). The larger the S/N ratio, the better was chosen to optimise the *C* value (Table 2b). The largest S/N ratio (35.58) was acquired for the WB pretreated and 4-mm thick slice at 90 W microwave powers.

In comparison, the smallest S/N ratio (33.65) was acquired for the AA pretreated and 6-mm thick slice at 360 W microwave power. This indicates that the pretreatment with WB and the 4-mm thick tomato slice at 90 W microwave power were the prime processing combination. Ilter et al. (2018) reported that the *C* value increased slightly with microwave power. The higher the *C* value, the higher the colour intensity of the dried tomato perceived by the consumers (Pathare et al., 2013). The response means of the S/N ratio for each level of the controlling factors in *C* (Table 3b) show that the pretreatment had the largest delta value; thus, the 1st rank was allocated to it followed by the thickness of the slice (the 2nd rank) and microwave power used (the 3rd rank). This indicates that the pretreatment used was the prime significant processing parameter controlling the chroma value of the dried tomato slice. The thickness of the slice and the microwave power followed, respectively.

Table 3b. The response means of the signal to noise (S/N) ratio for colour parameters of microwave oven drying.

	Pretreatment	Thickness	Microwave power
ΔE (using smaller the better)			
Level 1	-18.93	-22.03	-22.32
Level 2	-24.73	-23.22	-23.09
Level 3	-24.89	-23.31	-23.15
Delta	5.96	1.29	0.83
Rank	1st	2nd	3rd
BI (using smaller the better)			
Level 1	-31.10	-27.52	-27.75
Level 2	-27.87	-29.38	-26.69
Level 3	-24.46	-26.53	-28.99
Delta	6.64	2.84	2.30
Rank	1st	2nd	3rd
C (using larger the better)			
Level 1	35.24	35.18	35.05
Level 2	34.45	34.49	34.77
Level 3	34.75	34.77	34.62
Delta	0.80	0.69	0.44
Rank	1st	2nd	3rd
α (using larger the better)			
Level 1	-1.62	-1.65	-1.48
Level 2	-1.38	-1.55	-1.69
Level 3	-1.69	-1.48	-1.52
Delta	0.31	0.17	0.21
Rank	1st	3rd	2nd

Key: Level 1 = Water blanched, 4-mm thickness and 90 W microwave power; Level 2 = Ascorbic acid, 6-mm thickness and 180 W microwave power; Level 3 = Sodium metabisulphite, 8-mm thickness and 360 W microwave power.

The hue angle (*α*) (Table 2b) was slightly higher in the dried tomato than in the fresh samples. This indicates that less browning occurred in the dried samples. Hawlader et al. (2006) have reported that a decrease in the *α* value shows increased brown pigment formation and moving away from yellowness. It was observed that the changes in *α* values were not significant ($p>0.05$) compared to the drying processes. These results corroborated the previous studies by Maskan (2001) for microwave-dried kiwifruits, Ozkan et al. (2007) for microwave-dried spinach leaves and Arslan and Ozcan (2010) for microwave-dried onion. The larger the S/N ratio, the better was chosen to optimise the *α* value (Table 2b). The larger the S/N ratio, the better was chosen to optimise the α value (Table 2b). The largest S/N ratio (-1.21) was acquired for the AA pretreated and 6-mm thick slice at 360 W microwave power and the AA pretreated and 8-mm thick slice at 90 W microwave power. These were the prime processing combinations influencing the microwave-dried tomato hue value. The response means of the S/N ratio for each level of the controlling factors in α (Table 3b) show that the pretreatment of the slice had the largest delta value; thus, the 1st rank was allocated to it, followed by the microwave power used (the 2nd rank) and the thickness of the slice (the 3rd rank). This indicates that the slice pretreatment was the prime significant processing parameter controlling the hue value of the dried tomato slice. The microwave power used and the thickness of the slice followed, respectively.

Conclusion

The use of the Adobe Photoshop software for image analysis, followed by the optimisation of the processing conditions applying the Taguchi technique, was experimented. The results of the digital imaging colour measurements of dried tomato slices offer an adequate means of non-destructive colour analyses. The Taguchi technique provided optimum processing variables that produce the smallest change in the colour characteristics of microwave-dried tomato samples compared with fresh samples.

The pretreatment used was the prime significant processing parameter controlling the *L**, *b**, ΔE, BI, and hue values. At the same time, the slice thickness considerably influenced the *a**, ratio of *a*/b** and chroma values. These results showed that the Adobe Photoshop software for image analysis could be an alternative to sophisticated colour measurement instruments. This information will benefit tomato processors, which can be improved upon and adapted for bulk colour characteristics.

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OPTIMIZACIJA ANALIZE BOJE PARADAJZA OSUŠENOG MIKROTALASIMA PRIMENOM TAGUČIJEVE TEHNIKE

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Rezime

Prerađivači hrane i potrošači često brinu zbog nedosledne boje sušenog paradajza. Da bi se minimizirale štetne promene boje, parametri procesa trebalo bi da se optimiziraju. Tako je istražena digitalna slika pomoću softvera *Photoshop* i optimizacija Tagučijevom tehnikom da bi se odredila površinska boja kriški paradajza osušenih mikrotalasima. Uzorak paradajza je prethodno tretiran blanširanjem u vodi (VB), askorbinskom kiselinom (AK) i natrijum metabisulfitom (NB). Pored toga, uzorak je isečen na debljine od 4 mm, 6 mm i 8 mm i osušen mikrotalasnima snage 0W, 180W i 360W prema Tagučijevom eksperimentalnom dizajnu. Izmerene su karakteristike boje (L^*, a^*, b^*, promena boje, indeks posmeđivanja, nijansa i hroma) kriški sušenog paradajza. Vrednosti L^*, a^* i b^* svežeg paradajza bile su 56,73, 44,51 odnosno 38,38. Optimalni uslovi prerade za karakteristike boje značajno su varirali ($p<0{,}05$). Prethodni tretman je najvažniji parametar prerade koji kontroliše vrednosti L^*, b^*, ΔE, BI i nijanse. Istovremeno, debljina kriški je značajno uticala na vrednost a^*, odnos a^*/b^* i vrednosti intenziteta hrome. Digitalna slikovna merenja boja kriški sušenog paradajza obezbeđuju odgovarajući metod za nedestruktivnu analizu boje. Ovim saznanjima daje se mogućnost unapređenja i modifikacije prerađivačima paradajza u cilju prilagođavanja boje.

Ključne reči: analiza boja, mikrotalasno sušenje, kriška paradajza, *Adobe Photoshop*, Tagučijeva tehnika.

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